

**WHAT IS CLAIMED IS:**

1 1. A method for use in a multi-stage switch including  
2 - a number,  $k \times n$ , of output ports,  
3 - a plurality of central modules, and  
4 - a plurality of input modules, each including  $k$   
5 groups of  $n$  virtual output queues and outgoing links  
6 coupled with each of the plurality of central modules,  
7 for scheduling the dispatch of cells stored in the virtual  
8 output queues, the method comprising:  
9 a) matching a non-empty virtual output queue of an  
10 input module with an outgoing link in the input  
11 module, wherein the outgoing link has an associated  
12 master arbitration operation for selecting one of the  
13  $k$  groups of  $n$  virtual output queues; and  
14 b) matching the outgoing link with an outgoing link  
15 of one of the central modules.

1 2. The method of claim 1 wherein the act of matching a  
2 non-empty virtual output queue of an input module with an  
3 outgoing link in the input module includes:  
4 i) sending, on behalf of each non-empty virtual  
5 output queue, a request to slave arbiters, each  
6 of the slave arbiters being associated with one  
7 of each of the outgoing links of the input  
8 module, and each of the slave arbiters being  
9 associated with the group of virtual output  
10 queues to which the non-empty virtual output  
11 queue belongs;  
12 ii) sending, on behalf of each group of virtual  
13 output queues to which a non-empty virtual output  
14 queue belongs, a request to master arbiters, each

15 of the master arbiters being associated with one  
16 of each of the outgoing links of the input  
17 module;  
18 iii) selecting, with each of the master  
19 arbiters, a virtual output queue group having at  
20 least one non-empty virtual output queue, from  
21 among one or more virtual output queue groups  
22 that sent a request;  
23 iv) selecting, with each of the slave arbiters,  
24 a non-empty virtual output queue, belonging to  
25 its associated group, from among one or more  
26 virtual output queues that sent a request; and  
27 v) selecting, with the arbiter of the each of  
28 the selected non-empty virtual output queues of  
29 each of the selected virtual output queue groups,  
30 an outgoing link from among the one or more  
31 candidate outgoing links, each of the one or more  
32 candidate outgoing links being associated with a  
33 master arbiter that selected the virtual output  
34 queue group and a slave arbiter that selected the  
35 non-empty virtual output queue.

1 3. The method of claim 2 wherein the act of matching a  
2 non-empty virtual output queue of an input module with an  
3 outgoing link in the input module occurs within one cell  
4 time slot.

1 4. The method of claim 2 wherein an act of selecting, with  
2 a master arbiter, a virtual output queue group having at  
3 least one non-empty virtual output queue, is done in  
4 accordance with a round robin discipline.

1 5. The method of claim 2 wherein an act of selecting, with  
2 a slave arbiter, a non-empty virtual output queue,  
3 belonging to its associated group, is done in accordance  
4 with a round robin discipline.

1 6. The method of claim 2 wherein the act of selecting,  
2 with the arbiter of the each of the selected non-empty  
3 virtual output queues of each of the selected virtual  
4 output queue groups, an outgoing link from among the one or  
5 more candidate outgoing links, is done in accordance with a  
6 round robin discipline.

1 7. The method of claim 2 wherein the acts of  
2 i) sending, on behalf of each non-empty virtual  
3 output queue, a request to slave arbiters, each  
4 of the slave arbiters being associated with one  
5 of each of the outgoing links of the input  
6 module, and each of the slave arbiters being  
7 associated with the group of virtual output  
8 queues to which the non-empty virtual output  
9 queue belongs;  
10 ii) sending, on behalf of each group of virtual  
11 output queues to which a non-empty virtual output  
12 queue belongs, a request to master arbiters, each  
13 of the master arbiters being associated with one  
14 of each of the outgoing links of the input  
15 module;  
16 iii) selecting, with each of the master  
17 arbiters, a virtual output queue group having at  
18 least one non-empty virtual output queue, from  
19 among one or more virtual output queue groups  
20 that sent a request;

21           iv) selecting, with each of the slave arbiters,  
22           a non-empty virtual output queue, belonging to  
23           its associated group, from among one or more  
24           virtual output queues that sent a request; and  
25           v) selecting, with the arbiter of the each of  
26           the selected non-empty virtual output queues of  
27           each of the selected virtual output queue groups,  
28           an outgoing link from among the one or more  
29           candidate outgoing links, each of the one or more  
30           candidate outgoing links being associated with a  
31           master arbiter that selected the virtual output  
32           queue group and a slave arbiter that selected the  
33           non-empty virtual output queue,  
34   are performed at least twice within one cell time slot.

1   8. The method of claim 1 wherein the act of matching the  
2   outgoing link of the input module with an outgoing link of  
3   one of the central modules includes:

- 4           i) sending a request for the outgoing link of  
5           the input module to an arbiter for each of the  
6           outgoing links of the central modules that leads  
7           towards an output port associated with the  
8           virtual output queue matched with the outgoing  
9           link of the input module; and  
10          ii) selecting with the arbiter of each of the  
11          outgoing links of the central modules, an  
12          outgoing link of an input module from among those  
13          that sent a request.

1   9. The method of claim 8 wherein the act of selecting with  
2   the arbiter of each of the outgoing links of the central

3 module, an outgoing link of the input module that broadcast  
4 a request, is done based on a round robin discipline.

1 10. A method for use in a multi-stage switch including

2 - a number,  $k \times n$ , of output ports,  
3 - a plurality of central modules, and  
4 - a plurality of input modules, each including  $k$   
5 groups of  $n$  virtual output queues and outgoing links  
6 coupled with each of the plurality of central modules,  
7 for matching a non-empty virtual output queue of an input  
8 module with an outgoing link in the input module, the  
9 method comprising:

- 10 a) sending, on behalf of each non-empty virtual  
11 output queue, a request to slave arbiters, each of the  
12 slave arbiters being associated with one of each of  
13 the outgoing links of the input module, and each of  
14 the slave arbiters being associated with the group of  
15 virtual output queues to which the non-empty virtual  
16 output queue belongs;
- 17 b) sending, on behalf of each group of virtual output  
18 queues to which a non-empty virtual output queue  
19 belongs, a request to master arbiters, each of the  
20 master arbiters being associated with one of each of  
21 the outgoing links of the input module;
- 22 c) selecting, with each of the master arbiters, a  
23 virtual output queue group having at least one  
24 non-empty virtual output queue, from among one or more  
25 virtual output queue groups that sent a request;
- 26 d) selecting, with each of the slave arbiters, a  
27 non-empty virtual output queue, belonging to its  
28 associated group, from among one or more virtual  
29 output queues that sent a request; and

30 e) selecting, with the arbiter of the each of the  
31 selected non-empty virtual output queues of each of  
32 the selected virtual output queue groups, an outgoing  
33 link from among the one or more candidate outgoing  
34 links, each of the one or more candidate outgoing  
35 links being associated with a master arbiter that  
36 selected the virtual output queue group and a slave  
37 arbiter that selected the non-empty virtual output  
38 queue.

1 11. The method of claim 10 wherein the act of matching a  
2 non-empty virtual output queue of an input module with an  
3 outgoing link in the input module occurs within one cell  
4 time slot.

1 12. The method of claim 10 wherein an act of selecting,  
2 with a master arbiter, a virtual output queue group having  
3 at least one non-empty virtual output queue, is done in  
4 accordance with a round robin discipline.

1 13. The method of claim 10 wherein an act of selecting,  
2 with a slave arbiter, a non-empty virtual output queue,  
3 belonging to its associated group, is done in accordance  
4 with a round robin discipline.

1 14. The method of claim 10 wherein the act of selecting,  
2 with the arbiter of the each of the selected non-empty  
3 virtual output queues of each of the selected virtual  
4 output queue groups, an outgoing link from among the one or  
5 more candidate outgoing links, is done in accordance with a  
6 round robin discipline.

1 15. The method of claim 10 wherein the acts of  
2 a) sending, on behalf of each non-empty virtual  
3 output queue, a request to slave arbiters, each of the  
4 slave arbiters being associated with one of each of  
5 the outgoing links of the input module, and each of  
6 the slave arbiters being associated with the group of  
7 virtual output queues to which the non-empty virtual  
8 output queue belongs;  
9 b) sending, on behalf of each group of virtual output  
10 queues to which a non-empty virtual output queue  
11 belongs, a request to master arbiters, each of the  
12 master arbiters being associated with one of each of  
13 the outgoing links of the input module;  
14 c) selecting, with each of the master arbiters, a  
15 virtual output queue group having at least one  
16 non-empty virtual output queue, from among one or more  
17 virtual output queue groups that sent a request;  
18 d) selecting, with each of the slave arbiters, a  
19 non-empty virtual output queue, belonging to its  
20 associated group, from among one or more virtual  
21 output queues that sent a request; and  
22 e) selecting, with the arbiter of the each of the  
23 selected non-empty virtual output queues of each of  
24 the selected virtual output queue groups, an outgoing  
25 link from among the one or more candidate outgoing  
26 links, each of the one or more candidate outgoing  
27 links being associated with a master arbiter that  
28 selected the virtual output queue group and a slave  
29 arbiter that selected the non-empty virtual output  
30 queue,  
31 are performed at least twice within one cell time slot.

1 16. A combination for use in a multi-stage switch, the  
2 combination comprising:  
3 a) a plurality of central modules, each including  
4 outgoing links towards output modules including a  
5 plurality of output ports, the output modules  
6 collectively including  $k \times n$  output ports;  
7 b) a plurality of input modules, each including  
8 i)  $k$  groups of  $n$  virtual output queues, and  
9 ii) outgoing links coupled with each of the  
10 plurality of central modules;  
11 c) means for matching a non-empty virtual output  
12 queue of the input module with an outgoing link in the  
13 input module, the means for matching a non-empty  
14 virtual output queue of the input module with an  
15 outgoing link in the input module including  
16 i) master arbiters, each of the master arbiters  
17 being associated with one of the outgoing links,  
18 for selecting a group of virtual output queues  
19 from among those associated with a received  
20 request,  
21 ii) groups of slave arbiters, each group of  
22 slave arbiters being associated with one of the  $k$   
23 groups of  $n$  virtual output queues, for selecting  
24 a virtual output queue from among those  
25 submitting a request, and  
26 iii) virtual output queue arbiters, each virtual  
27 output queue arbiter being associated with one of  
28 the virtual output queues, for selecting an  
29 outgoing link from among those submitting a  
30 grant; and



31 d) means for matching the outgoing link of the input  
32 module with an outgoing link of one of the central  
33 modules.

1 17. The combination of claim 16 wherein the means for  
2 matching a non-empty virtual output queue of an input  
3 module with an outgoing link in the input module further  
4 include:

5 iv) means for sending, on behalf of each  
6 non-empty virtual output queue, a request to  
7 slave arbiters, each of the slave arbiters being  
8 associated with one of the outgoing links of the  
9 input module, and each of the slave arbiters  
10 being associated with one of the groups of  
11 virtual output queues; and  
12 v) means for sending, on behalf of each of the  
13 groups of virtual output queues to which a  
14 non-empty virtual output queue belongs, a request  
15 to master arbiters, each of the master arbiters  
16 being associated with one of the outgoing links  
17 of the input module.

1 18. The combination of claim 16 wherein the means for  
2 matching a non-empty virtual output queue of an input  
3 module with an outgoing link in the input module performs  
4 the match within one cell time slot.

1 19. The combination of claim 16 wherein each of the master  
2 arbiters operates in accordance with a round robin  
3 discipline.

1 20. The combination of claim 19 wherein each of the master  
2 arbiters operates independent of the others.

1 21. The combination of claim 16 wherein each of the slave  
2 arbiters operates in accordance with a round robin  
3 discipline.

1 22. The combination of claim 21 wherein each of the slave  
2 arbiters operates independent of the others.

1 23. The combination of claim 16 wherein each of the  
2 virtual output queue arbiters operates in accordance with a  
3 round robin discipline.

1 24. The combination of claim 23 wherein each of the  
2 virtual output queue arbiters operates independent of the  
3 others.

1 25. The combination of claim 16 wherein the means for  
2 matching a non-empty virtual output queue of the input  
3 module with an outgoing link in the input module performs  
4 multiple matching iterations within one cell time slot.

1 26. The combination of claim 16 wherein the means for  
2 matching the outgoing link with an outgoing link of one of  
3 the central modules include:

4 i) means for sending a request for the outgoing  
5 link of the input module to an arbiter for each  
6 of the outgoing links of the central modules that  
7 leads towards an output port associated with the  
8 virtual output queue matched with the outgoing  
9 link of the input module; and

10           ii) for each of the outgoing links of the  
11           central module, an arbiter for selecting an  
12           outgoing link of the input module from among  
13           those that sent a request.

1   27. The combination of claim 16 wherein there are:  
2           k input modules, each having n input ports, k  
3   groups of n virtual output queues, and m outgoing links.

1   28. An input module for use a multi-stage switch including  
2   a plurality of central modules, the input module  
3   comprising:

4       a) k groups of n virtual output queues;  
5       b) outgoing links coupled with each of the plurality  
6       of central modules; and  
7       c) means for matching a non-empty virtual output  
8       queue of the input module with an outgoing link in the  
9       input module, the means for matching a non-empty  
10      virtual output queue of the input module with an  
11      outgoing link in the input module including

12          i) master arbiters, each of the master arbiters  
13          being associated with one of the outgoing links,  
14          for selecting a group of virtual output queues  
15          from among those submitting a request,

16          ii) groups of slave arbiters, each group of  
17          slave arbiters being associated with one of the k  
18          groups of n virtual output queues, for selecting  
19          a virtual output queue from among those  
20          submitting a request, and

21          iii) virtual output queue arbiters, each virtual  
22          output queue arbiter being associated with one of  
23          the virtual output queues, for selecting an

24 outgoing link from among those associated with a  
25 received grant.

1 29. The input module of claim 28 wherein the means for  
2 matching a non-empty virtual output queue of an input  
3 module with an outgoing link in the input module performs  
4 such matching within one cell time slot.

1 30. The input module of claim 28 wherein each of the  
2 master arbiters is updated in accordance with a round robin  
3 discipline.

1 31. The input module of claim 30 wherein each of the  
2 master arbiters operates independent of the others.

1 32. The input module of claim 28 wherein each of the slave  
2 arbiters is updated in accordance with a round robin  
3 discipline.

1 33. The input module of claim 32 wherein each of the slave  
2 arbiters operates independent of the others.

1 34. The input module of claim 28 wherein each of the  
2 virtual output queue arbiters is updated in accordance with  
3 a round robin discipline.

1 35. The input module of claim 34 wherein each of the  
2 virtual output queue arbiters operates independent of the  
3 others.

1 36. The input module of claim 28 wherein means for  
2 matching a non-empty virtual output queue of an input

3 module with an outgoing link in the input module repeats  
4 such matching within one cell time slot.

1 37. The input module of claim 28 wherein there are k input  
2 modules, each having n input ports, and m outgoing links.

1 38. A machine readable medium having stored thereon  
2 information comprising:

3 a) a sequence of virtual output queue identifiers,  
4 each having an associated indicator indicating whether  
5 or not a request was received from the associated  
6 virtual output queue;

7 b) a first pointer pointing to one of the sequence of  
8 virtual output queue identifiers;

9 c) a sequence of virtual output queue group  
10 identifiers, each having an associated indicator  
11 indicating whether or not a request was received from  
12 the associated virtual output queue group; and

13 d) a second pointer pointing to one of the sequence  
14 of virtual output queue group identifiers.